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STATUS OF THE ELECTRON LENS FOR SPACE CHARGE COMPENSATION IN SIS18*

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Abstract

At GSI a project has been initiated to investigate the option of space charge compensation (SCC) by use of an electron lens in order to overcome space charge (SC) limits in the synchrotrons SIS18 and SIS100 for the Facility for Antiproton and Ion Research (FAIR).

The repeated crossing of resonance lines due to the synchrotron motion in bunched beams is considered one of the main drivers of SC induced beam loss in the synchrotrons. Electron lenses provide a compensation of ion beam SC by virtue of their negative charge interacting with the ions in the overlap region while a time-varying compensation can be achieved by the modulation of the electron beam.

In order to demonstrate space charge compensation of bunched ion beams, an electron lens is under development for the application in SIS18.

In this contribution, the status of the electron lens design will be reported putting special emphasis on its main components: the RF modulated electron gun, that is being developed within an ARIES collaboration, and the magnet system.

INTRODUCTION

FAIR is a multipurpose accelerator facility that will provide stable and rare isotope beams covering a wide range of intensities and beam energies. A unique feature offered by the accelerators of FAIR will be the high intensities of primary hadron beams. As space charge represents a major intensity limitation in synchrotrons operating at low or medium energies, a new concept of (partial) SC compensation by pulsed electron lenses is under development, in order to further increase the beam intensities beyond FAIR reference parameters [1].

In low energy hadron accelerators SC compensation by electron lenses is challenging because the ion beam is bunched. For this reason an ideal compensation requires an electron beam longitudinally modulated at the bunch frequency, taking into account the variation of the bunch structure during the acceleration cycle, while keeping the transverse electron beam profile matched to that of the ion beam. Besides the challeging requirements of the modulation, a high electron beam current is needed which results in strong guiding fields of the lens. The requirements for the SCC electron lens are summarized in Table 1.

Table 1: SCC Electron Lens Requirements

Peak electron current	10 A
Extraction voltage	30 kV
Magnetic field	0.6 T
Interaction length	3.36 m
Horizontal beam radius	35 mm
Vertical beam radius	20 mm
Min. modulation frequency	0.4 MHz
Max. modulation frequency	1 MHz
Modulation bandwidth	10 MHz

Currently, an electron lens is under preparation to demonstrate the space charge compensation scheme in the synchroton SIS18. The prupose will be the validation of longitudinal and transverse matching of the two beams. With one electron lens a beam-beam tune shift of $\Delta Q_y^e = 0.1$ at injection energy is feasible. In the following the design and development status of critical lens components will be described.

STATUS OF ELECTRON LENS DESIGN

Magnetic Layout

The geometry of the electron lens is based on the layout of the existing SIS18 electron cooler as it has been designed for providing maximum interaction length taking into account the constraints of the SIS18 lattice.

The magnet systems of the electron lens comprises normal conducting magnets, solely, as the gun and collector solenoid, two toroids to guide the beam into and out of the main solenoid and additional solenoids to transfer the electron beam from the gun into the bending system and from the last bend to the beam dump. For the magnetic modelling CST STUDIO 3D EM studio was used.

The magnet system and the absolute value of magnetic field on the ion beam and the electron beam orbit are presented in Fig. 1. Each magnet has an iron casing of (soft) iron with a conductivity of $1.04\,10^7$ S/m.

The gun and transfer solenoids are designed for an maximum axial magnetic field of 0.6 T and the coils have a total length of 314 mm each with an aperture of 200 mm. Two 45° toroids with a central length of 1 167 mm and maximum magnetic field of 0.6 T are designed to bend the electron beam on to and deflect from the interaction section. The

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toroidal coils have a rectangular cross section in order to leave enough space for dipole correction coils, vacuum chambers, flanges for pumps and clearing electrodes [2].

The main solenoid is designed for the maximum magnetic field of 0.6 T and the current density is 5.62 A/mm^2 [3]. The length of the solenoid including the iron casing is 3 360 mm, and the inner diameter of its aperture is 150 mm.

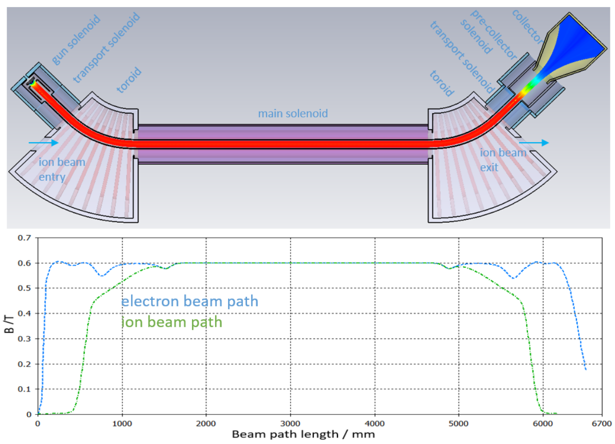

Figure 1: The SCC electron lens magnet system and the absolute value of magnetic field on the ion beam and the electron beam orbit.

Ion Orbit Correctors

As a consequence of the necessity to guide the electron beam onto a path parallel to the ion beam and deflect it from this path again, there is a strong vertical field component perpendicular to the motion of the ion beam in both toroid sections. For this reason four correction dipoles have been introduced in the magnetic design, two are integrated into the toroids. The dipoles have to correct a vertical magnetic field of 0.3 T corresponding to a total deflection angle of almost 12° for light ions (C^{6+}, 11.4 MeV/u). The maximum design field of the corrector dipoles is B = 0.65 T.

Collector

For the collector design it is necessary to minimize the beam power by putting it on cathode potential. At the same time some positive bias is required to ensure high catching efficiency. The beam is distributed over the collector by an appropriately shaped magnetic field of a seperate pre-collector solenoid, and repeller electrodes prevent SEE electrons from entering the electron lens. The preliminary design value for the disspated power in the collector is 30 kW referring to a potential difference between gun cathode and collector of 3 kV. However, the design process is still ongoing in particular taking into account the beam potential of the realistic electron beam distribution.

RF Modulated Electron Gun

The RF modulated electron gun is being developed within the ARIES collaboration. Its design is tailored to the needs of the demonstrator lens for space charge compensation in SIS18, which is supposed to support operation with matched transverse electron distributions [4]. Beyond the scope of ARIES, the design of a RF modulated gun with homogeneous electron distribution is in progress.

The beam modulation with respect to required beam currents and resulting extraction voltages represented a major challenge in the design of the electron gun. The modulation by a grid which is placed close to the cathode and therefore reduces the needed voltages (max. 3 kV) to suppress the electron current was chosen to be the most suitable solution. The prototype electron gun design (called TE^2) is based on the layout of a volume type ion source that can in principal be devided in plasma generator and extractor part. The plasma generator stays unchanged and generates an arc discharge to directly heat the cathode. The electrodes of the extractor part are replaced by a Gaussian shaped cathode and grid (both manufactured of tungsten) as well as the anode (copper). Figure 2 displays a picture of the actual electron gun and the related technical drawing.

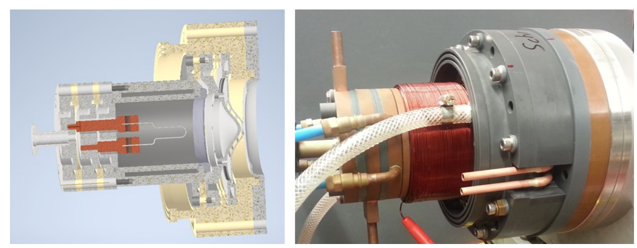

Figure 2: Technical drawing (left) and actual electron gun (right).

Using an existing ion source design has many advantages: it is a proven design and therefore, spacing and layout of several parts is already optimized regarding high voltage breakdowns (30 kV), vacuum conditions and outside isolation. Due to its flexible design it is possible to adapt changes and modifications quickly. Furthermore, the hot tungsten as electron emitter makes the electron gun very robust [5].

The gun has to be positioned in the centre of a solenoid where the magnetic field is considered to be homogeneous with a maximum field of B_z = 0.6 T on axis. Since the gun has to to be electrically isolated from the solenoid, a redesign of the outer insulation as well as the cooling system of the anode flange had to be performed. The parts for the integrated setup are currently being manufactured.

A picture of the gun solenoid designed and manufactured by Scanditronix Magnet AB and the integrated electron gun setup is depicted in Fig. 3. In order to shape the round beam eliptically, the design and integration of a quadrupol into the electron gun set-up is under preperation.

The requirements on the power modulator design are high since the electron beam needs to be RF modulated at a bandwidth of several MHz with time varying amplitude ranging from DC to fully modulated, while the transverse size needs to be continuously adapted to the adiabatically shrinking ion beam. For this reason, an iterative engineering approach was chosen [6]: several scaled power modulator versions

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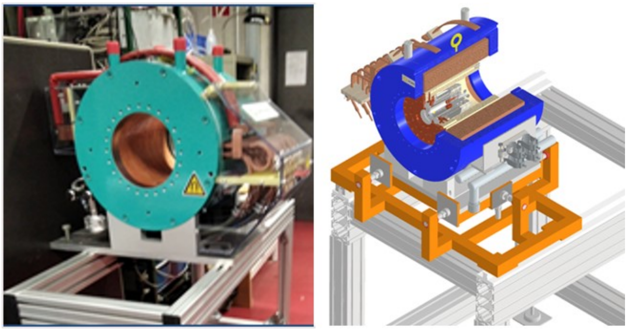

Figure 3: Picture of gun solenoid (left) and technical drawing of integrated electron gun set-up (right).

were built and the performance was validated during joint experiments of the colleagues from Riga Technical University and Goethe-University at the Institute for Applied Physics in Frankfurt.

The topology for the final modulator was chosen to be a semiconductor multi-level RF inverter feeding the grid-cathode capacitance from a distance by a twisted pair high voltage feeder. In the final modulator design 26 RF inverters are connected in series providing an output signal up to 150 V each. They are switched on or off to generate the prescribed waveform. For smoothing of the waveform output signal filtering is used. Figure 4. shows the working principle and a scaled version of the power modulator. The design values of the RF modulated electron gun are summarized in Table 2.

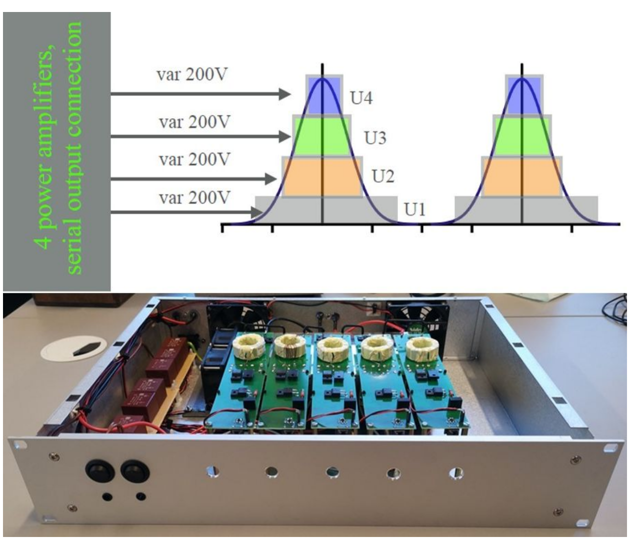

Figure 4: Working principle of multi-level inverter and picture of scaled (4-level) power modulator.

Test Stand

To perform experiments with modulated intense electron beams, a dedicated test stand is required that is currently under construction at the Institute of Applied Physics in Frankfurt. The gun is powered on a high voltage-platform (max. −35 kV) as the solenoid stays on ground potential.

Table 2: Design Values of the RF Modulated Electron Gun

Max. extracted electron current	10 A
Anode voltage	30 kV
Magnetic field	0.6 T
Cathode radius	26.5 mm
Min. distance cathode to anode	20 mm
Distance cathode to grid	3 mm
Grid-cathode capacity	100 - 125pF
Max. grid voltage	3.2 kV
Waveform frequency sweep	0.4 - 1MHz
Modulation bandwidth	10 MHz

Between gun solenoid and dump solenoid there is space for non-interceptive beam diagnostics. Furthermore, a beam dump for electron current measurement and controlled power deposition will be installed. An energy recovering system recycles the beam power of about 300 kW. A schematic overview of the planned setup is shown in Fig. 5. In a further step, a two meter long transport section which also offers space for diagnostics will be installed.

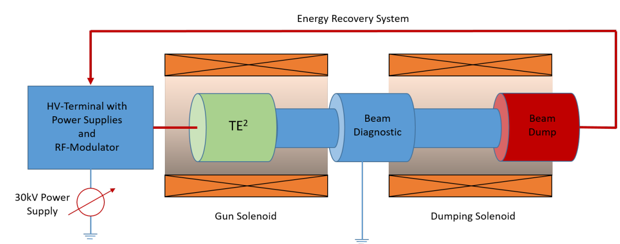

Figure 5: Schematic overview of the electron gun test bench.

CONCLUSION AND OUTLOOK

The layout of the major magnets of the electron lens as toroids, solenoids and ion beam orbit correctors is completed. The collector design including the pre-collector magnet is well advanced and beam dynamic studies are ongoing.

The electron gun is manufactured and currently integrated into the solenoid while the power modulator is under construction. Furthermore, the manufacturing of test bench components for testing the RF modulated electron gun is in progress as well as the preparation of IT infrastructure and controls of the experiment. The HV terminal will be completed by the end of Q2. First beam experiments with low currents can be expected at the beginning of Q3 and experiments with full beam by the end of this year.

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